Drought-induced Changes in Chlorophyll Stability Index, Relative Water Content and Yield of Cotton Genotypes

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Abstract: Background: It is well known that water scarcity limits crop production and further expansion of agriculture. Cotton cultivars that can endure and recover from drought are needed to minimize yield loss in dry land areas and to reduce the water needs of irrigated production. Several efforts have been taken to improve cotton production under water limiting conditions through conventional breeding techniques. However, progress in traditional breeding approach has been slow due to limited knowledge on genetics of drought tolerance and involvement of several complex tolerance mechanisms. **Objective:** A study was conducted to determine the association analysis of biochemical and yield parameters related to water stress in cotton. **Results:** The experiment was conducted by adopting Factorial Randomized Block Design with three replications. The treatments comprised of water stress imposed at vegetative, squaring and boll development stages of crop growth.

Key words: Chlorophyll stability index, relative water content, yield

INTRODUCTION

Water deficit or drought stress is a severe environmental factor and the major constraint on plant productivity with an evident on plant growth. *Gossypium hirsutum* L. and *Gossypium barbadense* L. are the two predominant elite cotton species, usually grown during the summer in arid and semiarid regions where water availability is often limited. Regardless of whether it is irrigated or not, cotton is often exposed to drought, which adversely affects both yield and lint quality. Chlorophyll stability is a function of temperature and it is found to correlate with drought tolerance. Chlorophyll stability index is a measure of integrity of membrane or heat stability of the pigments under stress conditions (Kaloyereas, 1958). The CSI is a single parameter used to measure frost (or) drought resistance of a plant. Sairam *et al.* (1996) reported that both drought stress and temperature stress decreased membrane stability, chlorophyll content and chlorophyll stability index in all wheat genotypes. The high chlorophyll stability indices help the plants to withstand stress through better availability of chlorophyll. This leads to increased photosynthetic rate and more dry matter production (Madhan Mohan *et al.*, 2000). The Relative Water Content (RWC) was studied in drought tolerant and drought sensitive genotypes of cotton (*G. hirsutum* L.) during induction of water stress and posterior recovery

(Parida *et al.*, 2008). In case of drought tolerant genotype, the leaves maintained higher RWC and photosynthetic activities under water stress than that of drought sensitive genotype. Flower and Ludlow (1986) proposed that RWC is an alternative measure of plant water status which tells upon the metabolic process in the tissue and lethal leaf water status. Upreti *et al.* (1997) noted changes in RWC under stress and normal conditions, the reduction being significant under stress condition. Crop management for both optimum yield and fibre quality is a realistic and important approach to take for a profitable cotton production system. Water availability is arguably the most limiting factor to profitable cotton production in the South East. Pace *et al.* (1999) suggested cotton cultivars that can endure and recover from drought are needed to minimize fruit loss and reduce the amount of water required for crop production. Minimum numbers of flowers were found when moisture stress was imposed at flowering stage (Kaur and Singh, 1992). Jordan (1983) reported higher rate of square and boll shed in cotton due to water stress. Varma (1975) reported more than 32% of flower shedding and 58% of boll shedding in cotton. Kaur and Singh (1992) found that flower number and percentage of boll abscission were decreased by water stress at flowering stage of cotton. Seed cotton yield decreased as the allowable water deficit increased (Cudrak and Reddell, 1988). Lint yield is generally reduced because of reduced boll production, primarily because of

fewer flowers and also due to increased boll abortions when the stress is extreme and when it occurs during reproductive growth (Pettigrew, 2004). Seed yield and yield components are severely affected by water deficit.

MATERIALS AND METHODS

The aim of this experiment was to investigate the responses caused by progressive water stress and the necessary time for have biochemical and physiological changes of *Gossipium* spp. during the vegetative, squaring and boll development stages. For present investigation, 21 genotypes including 8 parents, 4 F₁ hybrids, 5 F₂'s and 4 back crosses along with parents were subjected for genetic diversity analysis using physiological features. Field trails were conducted in Kharif 2008 in the Department of Cotton, Centre for Plant Breeding and Genetics, TNAU, Coimbatore.

Treatments:

- T₁: Control
- T₂: Stress at vegetative
- T₃: Stress at squaring
- T₄: Stress at boll development

Chlorophyll stability index was calculated by the method described as Relative Water Content (RWC) by Murthy and Majumdar (1962).

$$RWC = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

RESULTS AND DISCUSSION

The chlorophyll stability index is an indicative of the maintenance of photosynthetic pigments under drought situation. KC 2×MCU 13 in both F₁ and F₂ generation have recorded higher values (68.36 and 74.47) at boll development stage than the rest of the combinations and parents irrespective of treatments, indicating that this combination posses drought tolerance characteristics (Table 1). Stress given at vegetative and squaring stages invariably show reduction in CSI. Among the genotypes the KC 2 and AS 2 maintained a good mean values (71.89, 73.31 and 75.22; 68.26, 68.74 and 70.62 at vegetative, squaring and boll development stages, respectively) which indicates that these two genotypes are able to withstand drought condition. On the other hand, the genotype MCU 13 and KC 3 was found to rank the medium indicating the moderately tolerant nature as for as the moisture stress is concerned. The susceptible genotype Surabhi, showed the lowest mean value of

56.13, 58.41 and 61.36 at vegetative, squaring and boll development stages, respectively. The high chlorophyll stability indices help the plants to with stand stress through better availability of chlorophyll. This leads to increase photosynthetic rate and more dry matter production (Madhan Mohan *et al.*, 2000). Relative water content which is an important parameter for drought studies was recorded in F₁, F₂, F₃ and Back cross generations along with parents (Table 2). In general it was observed that RWC is maintained at higher level in KC 2×MCU 13 followed by KC 2×JKC 770 and AS 2×JKC 770 in both F₁ and F₂ generations. This indicates that these three combinations are superior in terms of drought tolerance. The genotype (KC 2×MCU 13)×KC 2 maintained a higher relative water content in all stages than others even under the stress conditions (76.43, 78.84 and 77.38). Plant water stress was measured in terms of leaf water potential or leaf relative water content (Deivanai *et al.*, 2010). Reduction in RWC result in loss of turgidity, which leads to stomatal closure and reduced photosynthetic rates (Lv *et al.*, 2007). The performance of genotypes for RWC (%), under water deficit condition, in which a sharp decline in RWC was recorded among the genotypes. Some previous studies (Jamaux *et al.*, 1997; Altinkut *et al.*, 2001; Colom and Vazzana, 2003) have shown that maintenance of a relatively high RWC during mild drought is an indicative of drought tolerance. Among the genotypes KC 2, AS 2 and MCU 13 recorded higher value of RWC percentage at all the stages of crop growth irrespective of the treatments (77.28, 79.06 and 79.37; 74.80, 77.02 and 77.78; 71.46, 75.07 and 75.63, respectively). However, the susceptible genotype Surabhi exhibited the lowest relative water content percentage of 61.45, 64.89 and 64.39 than other genotypes. RWC is maintained at higher level in KC 2×MCU 13 followed by KC 2×JKC 770 and AS 2×JKC 770 in both F₁ and F₂ generations.

Differences were noticed in seed cotton yield per plant due to the treatments. The stress imposed at squaring stage has shown a marked reduction in seed cotton yield when compared to the control. The seed cotton yield recorded as 128.99 in KC 2×MCU 13 (F₂) irrespective of treatments. Significant differences were also observed between the genotypes, treatments and their interactions. The genotypes KC 2 and AS 2 have the highest value of seed cotton yield (120.28 and 110.22) than other genotypes at all stages irrespective of the treatmental effects (Table 3). Among the backcrosses, (KC 2×MCU 13)×MCU 13 the tolerant genotype exhibited the highest seed cotton yield of 92.59. Maximum number of flowers and bolls produced were found to be highest in KC 2, AS 2 and MCU 13 followed by Suvin, AS

Table 1: Effect of drought on Chlorophyll Stability Index (CSI %) at different stages of cotton in F₁, F₂, back crosses along with parents

Genotypes	Stages														
	Vegetative					Squaring					Boll development				
	T ₁	T ₂	T ₃	T ₄	Mean	T ₁	T ₂	T ₃	T ₄	Mean	T ₁	T ₂	T ₃	T ₄	Mean
Parents															
MCU 13	69.50	58.27	63.32	59.20	62.55	68.22	69.63	62.29	71.39	64.92	78.39	69.38	70.82	68.29	66.86
AS 2	74.33	59.39	68.13	71.20	68.26	69.29	72.65	64.92	70.48	68.74	78.39	74.38	76.29	72.27	70.62
JKC 770	68.07	63.29	63.17	69.38	66.73	65.29	66.26	60.39	65.64	64.99	73.28	70.73	69.29	69.28	66.73
KC 2	74.48	70.21	71.58	71.28	71.89	76.31	78.28	71.45	74.29	73.31	83.29	79.83	78.39	78.53	75.22
AS 1	64.26	62.38	68.06	64.47	66.04	65.17	66.28	55.39	70.26	65.26	69.12	69.28	65.29	69.26	66.11
Surabhi	56.59	52.36	53.69	61.87	56.13	61.19	63.27	58.38	62.25	58.41	73.12	70.28	63.27	68.27	61.36
KC 3	66.56	61.98	70.36	62.56	65.37	65.39	66.29	57.27	68.39	64.91	70.72	69.97	65.39	67.28	65.89
Suvin	66.29	61.23	70.09	69.85	66.87	68.29	69.28	56.92	70.20	66.56	75.18	73.25	67.92	72.28	68.16
F₁ hybrids															
AS1×Suvin	58.23	54.21	54.27	56.18	55.72	69.39	69.19	60.64	63.30	67.30	74.33	67.88	72.34	65.34	63.31
KC 2×MCU 13	63.32	54.87	59.28	60.27	59.44	77.39	68.92	64.67	67.29	71.22	80.21	75.33	78.23	76.65	68.36
AS 2×MCU 13	60.72	57.28	59.72	58.12	58.96	67.87	65.28	61.98	61.59	68.28	76.43	69.75	74.34	68.34	64.90
KC 2×JKC 770	63.91	58.28	61.28	65.18	62.16	76.28	73.39	67.68	70.45	78.20	86.54	80.54	83.24	78.88	71.86
F₂ hybrids															
KC 2×MCU 13	73.43	67.12	76.56	70.38	71.87	80.81	76.88	72.19	73.34	73.62	81.1	74.38	75.46	75.45	74.47
AS 3×JKC 770	74.55	68.73	70.56	78.33	73.79	78.19	72.18	74.39	83.45	75.24	82.19	73.20	84.35	70.67	75.92
AS 2×MCU 13	64.24	58.34	65.56	66.28	63.61	73.56	65.18	72.18	77.56	67.39	72.91	70.87	74.35	65.58	68.40
KC 2×JKC 770	76.88	74.35	77.76	75.55	76.14	85.45	82.18	73.29	84.89	78.50	88.32	80.92	85.19	82.64	80.15
AS 1×Suvin	62.45	56.34	66.56	60.65	61.50	71.23	65.27	70.10	80.65	66.08	82.51	79.30	76.29	78.39	69.81
Back crosses															
(AS2×MCU13)×MCU13	62.30	52.19	55.49	57.30	58.32	68.56	69.20	64.24	67.47	62.34	78.2	74.55	73.62	72.20	65.86
(KC2×MCU13)×KC2	66.78	63.83	65.29	67.45	65.84	74.39	73.49	63.54	71.28	67.99	82.76	78.92	76.90	75.20	70.98
(AS2×MCU13)×AS2	66.72	64.20	64.72	69.37	66.25	76.55	75.56	66.89	73.92	69.35	81.43	78.30	77.83	74.38	71.82
(KC2×MCU13)×MCU13	64.93	62.87	60.71	63.29	62.95	71.3	70.85	62.15	68.90	65.33	78.56	75.55	73.33	70.47	67.94
Mean	66.60	61.03	65.06	65.63	64.78	71.91	70.66	64.81	71.29	68.47	78.43	74.12	74.39	72.36	69.27

	Stages								
	Vegetative			Squaring			Boll development		
	T	G	T×G	T	G	T×G	T	G	T×G
SED	1.982	2.250	4.500	0.930	2.132	4.265	1.015	2.326	4.652
CD (p = 0.05)	1.938	4.421	8.871	1.837	4.211	8.422	2.004	4.652	9.186

Table 2: Effect of drought on relative water content (RWC %) at different stages of cotton in F₁, F₂, back crosses along with parents

Genotypes	Stages														
	Vegetative					Squaring					Boll development				
	T ₁	T ₂	T ₃	T ₄	Mean	T ₁	T ₂	T ₃	T ₄	Mean	T ₁	T ₂	T ₃	T ₄	Mean
Parents															
MCU 13	72.39	68.87	70.39	71.19	71.46	80.53	76.29	72.20	74.28	75.07	81.43	74.27	80.29	72.18	75.63
AS 2	76.46	74.23	69.30	79.20	74.80	82.27	78.29	80.52	78.11	77.02	80.15	80.54	78.39	79.65	77.78
JKC 770	67.18	64.39	64.33	67.29	65.80	71.34	65.25	67.52	64.27	66.37	64.71	67.10	71.40	63.20	66.44
KC 2	78.62	73.93	76.43	80.12	77.28	80.21	79.32	80.39	85.20	79.06	79.87	78.13	84.38	78.27	79.37
AS 1	68.29	55.64	62.39	73.28	64.90	76.23	76.29	78.44	78.76	70.47	78.45	65.39	72.10	72.54	70.94
Surabhi	66.26	56.49	66.73	65.32	61.45	70.23	72.21	66.23	68.12	64.89	63.38	56.46	67.43	65.28	64.39
KC 3	77.82	73.33	73.39	70.91	73.86	80.63	78.65	79.26	82.10	76.66	75.27	80.64	79.87	78.02	77.17
Suvin	69.46	65.21	65.47	71.21	68.09	82.10	79.43	78.90	82.87	73.75	71.02	79.76	64.42	76.32	73.50
F₁ hybrids															
AS1×Suvin	75.48	66.48	74.44	73.22	72.41	76.39	72.33	68.24	70.22	72.13	70.88	74.22	76.77	70.88	72.43
KC 2×MCU 13	82.10	78.39	78.92	73.20	78.15	84.30	79.93	78.39	74.12	78.61	76.40	75.40	78.88	73.76	77.90
AS 2×MCU 13	83.15	79.39	72.10	68.32	75.74	80.21	78.53	77.28	76.10	76.76	74.10	72.22	75.44	75.66	76.07
KC 2×JKC 770	81.22	80.62	77.39	78.33	79.39	76.38	83.20	78.30	80.22	79.45	72.32	70.33	83.22	71.10	77.96
F₂ hybrids															
KC 2×MCU 13	80.34	80.12	78.22	82.43	80.28	82.12	80.54	79.56	79.20	80.31	78.30	78.28	70.45	69.30	78.53
AS 3×JKC 770	83.33	81.42	80.15	84.54	82.36	83.21	82.54	84.42	85.30	83.03	79.25	84.76	72.40	67.48	81.01
AS 2×MCU 13	78.66	78.26	79.10	74.67	77.67	79.34	80.24	76.45	78.64	78.11	72.10	74.88	68.29	74.30	76.48
KC 2×JKC 770	84.56	82.10	82.16	85.27	83.52	85.78	86.43	84.56	79.22	83.73	84.52	85.12	80.44	78.71	83.29
AS 1×Suvin	73.44	73.21	74.42	68.29	72.34	77.80	74.90	74.24	77.29	73.99	65.39	68.24	76.34	62.84	72.34
Back crosses															
(AS2×MCU13)×MCU13	73.32	72.23	69.50	73.42	72.12	77.93	76.30	75.49	76.39	74.08	71.10	65.93	65.40	68.30	72.25
(KC2×MCU13)×KC2	78.93	75.32	75.83	75.64	76.43	83.52	82.10	81.10	80.65	78.84	76.37	73.30	73.20	72.11	77.38

Table 2: Continue

Genotypes	Stages														
	Vegetative					Squaring					Boll development				
	T ₁	T ₂	T ₃	T ₄	Mean	T ₁	T ₂	T ₃	T ₄	Mean	T ₁	T ₂	T ₃	T ₄	Mean
	T	G	T×G	T	G	T×G	T	G	T×G	T	G	T×G	T	G	T×G
(AS2×MCU13)×AS2	74.28	70.46	72.39	75.49	73.16	81.29	79.30	78.40	82.65	76.38	73.76	70.21	67.44	69.57	74.63
(KC2×MCU13)×MCU13	71.02	68.48	69.46	73.45	70.60	75.72	74.29	76.39	76.40	72.87	70.10	68.30	67.19	65.49	71.41
Mean	76.01	72.31	72.98	74.51	73.90	79.41	77.92	76.97	77.62	75.79	74.23	73.50	73.99	71.66	75.09
Genotypes	Stages														
	Vegetative					Squaring					Boll development				
	T ₁	T ₂	T ₃	T ₄	Mean	T ₁	T ₂	T ₃	T ₄	Mean	T ₁	T ₂	T ₃	T ₄	Mean
	T	G	T×G	T	G	T×G	T	G	T×G	T	G	T×G	T	G	T×G
SED	0.926	2.122	4.245	0.934	2.142	4.284	0.890	2.040	4.081						
CD (p = 0.05)	1.829	4.190	8.381	1.846	4.229	8.459	1.758	4.029	8.058						

Table 3: Effect of drought on yield components of cotton in F₁, F₂, back crosses along with parents

Genotypes	Yield parameters									
	No. of flowers per plant					Seed cotton yield (g pL ⁻¹)				
	T ₁	T ₂	T ₃	T ₄	Mean	T ₁	T ₂	T ₃	T ₄	Mean
Parents										
MCU 13	52.8	49.5	46.9	48.6	49.50	108.23	94.59	85.45	88.27	96.09
AS 2	45.7	44.4	41.2	42.5	43.50	126.43	112.34	94.82	107.29	110.22
JKC 770	38.3	26.1	22.6	24.1	27.80	103.68	95.48	77.29	86.30	90.69
KC 2	73.2	62.1	51.5	56.2	60.30	133.16	123.16	108.17	128.32	120.28
AS 1	57.6	51.3	46.6	49.4	51.20	118.63	110.35	93.76	99.59	105.58
Surabhi	44.2	42.6	41.3	43.4	42.60	93.60	86.90	62.90	78.34	80.44
KC 3	48.9	46.5	43.2	44.8	45.90	102.00	96.40	89.76	95.20	95.50
Suvin	59.6	55.5	52.5	54.2	54.80	102.00	96.40	89.76	95.20	95.50
F₁ hybrids										
AS1×Suvin	37.5	35.5	33.6	35.0	35.40	99.960	83.27	73.10	70.38	81.68
KC 2×MCU 13	63.3	52.7	45.7	48.9	52.65	144.824	88.39	95.33	120.29	112.21
AS 2×MCU 13	26.8	26.0	22.7	25.0	25.13	68.432	64.29	57.33	61.21	62.82
KC 2×JKC 770	42.8	41.7	40.7	41.5	41.68	92.778	79.39	68.34	72.29	78.20
F₂ hybrids										
KC 2×MCU 13	55.3	49.6	46.1	48.2	49.80	157.973	121.23	116.38	120.38	128.99
AS 3×JKC 770	33.8	32.3	28.9	31.2	31.55	58.045	42.66	35.34	49.72	46.44
AS 2×MCU 13	34.5	33.1	29.3	31.2	32.03	89.110	60.72	54.22	63.54	68.01
KC 2×JKC 770	36.1	35.2	31.7	32.9	33.98	69.090	55.28	45.23	54.46	56.25
AS 1×Suvin	54.7	54.2	49.5	52.6	52.75	140.008	99.82	103.29	122.26	116.28
Back crosses										
(AS2×MCU13)×MCU13	37.1	35.2	33.2	34.1	34.90	71.968	66.23	65.29	66.39	67.47
(KC2×MCU13)×KC2	24.4	23.0	21.2	21.6	22.55	81.263	60.38	62.28	57.19	65.28
(AS2×MCU13)×AS2	39.6	37.4	36.2	26.9	35.03	65.800	58.92	42.10	55.10	55.48
(KC2×MCU13)×MCU13	57.9	56.4	53.2	53.8	55.33	108.000	92.88	78.36	85.12	92.59
Mean	45.91	42.4	38.94	40.29	41.83	101.670	85.19	76.12	84.61	86.95
Yield parameters										
No. of flowers per plant										
Seed cotton yield (g pL ⁻¹)										
T										
G										
T×G										
SED	1.584	0.691	3.198	3.632	1.585	7.264				
CD (p = 0.05)	3.127	1.365	6.255	7.171	3.129	14.342				

1 and KC 3 in parental genotypes. According to Anderson (1972), water deficit at flowering and pollination (60-70 DAS) even for a short period resulted in an irreversible damage to plant and lowered the yield. Later experiments conducted by Singh and Sahay (1992) also supported this view. Seed cotton yield ultimately is the result of plant population, photosynthetic ability of the plants in community, number of flowers and number of bolls. Yield was remarkably reduced when stress was

imposed at squaring stage. Earlier report also indicated that the most critical phenophase for water stress in cotton is flowering (Singh and Sahay, 1992).

CONCLUSION

The study has paved way to utilize the most reliable parameter such as chlorophyll stability index and relative water content for screening drought tolerance. These

parameters can be regarded as selection indices to pick up the most tolerant genotype from a large number of population by the breeders. The investigation has opened new vistas for development of a quantifiable drought index for further exploitation. Based on the study, the cross combination KC 2×MCU 13 generation may be further advanced and released as a variety for commercial exploitation after proper evaluation.

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